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Procedia Engineering 40 (2012) 20 – 25

Procedia Engineering

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Steel Structures and Bridges 2012

Influence of rheological behaviour on load-carrying capacity of timber-concrete composite beams under long term loading

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Abstract

Wood and concrete are materials with different time dependent behaviour and both have different reactions to thermal and humidity changes of environment. In timber-concrete composite beams it results in generation of inelastic strains and redistribution of stress in cross-section.

To determine load carrying capacity of composite wood-concrete element is possible according to Additions B of EN 1995-1-1, Design of Timber Structures. But this calculation technique does not consider the influence of rheological properties of composite materials as shrinkage, eventually bulking of materials, the influence of composite on creep coefficient and the influence of environmental changes. In this paper, the analytical calculation model of long term behavior of the timber-concrete composite beams is presented, which considers the most significant rheological phenomena such as: viscous-elastic creep of concrete and wood, mechano-sorptive creep of wood, creep of shear connection, concrete shrinkage and strains due to thermal and relative humidity changes of environment. This model is applicable for simple beams with linear material properties and allows determining the final deflection in the middle span and stressing distribution in the middle cross- section of the composite beams affected by long term loading. Applying the presented calculation model and results of experimental tests, the analysis of rheological behavior influence on long term load carrying capacity of timber-concrete beams is described as well.

Keywords: timber-concrete; long term loading; rheological behavior

1. Introduction

Timber-concrete composite elements are more and more often used to create bearing structure of the floor decks in modern timber buildings and they are also applicable in design of timber bridges. As wood and

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doi:10.1016/j.proeng.2012.07.049

concrete are materials with several time dependent mechanical and physical behaviour it is very important to pay attention also to rheological behaviour of timber-concrete composite elements.

Under constant conditions, the effect of creep takes place in the wood and changes of environmental conditions affect the mechano-sorptive creep. The deformation of concrete in time is basically influenced by both creep and shrinkage. The interaction of these materials in composite elements is affected by the stiffness of connection and long-term behaviour of shear connection. Wood and concrete are materials with different behaviour in time and different reaction to thermal and humidity environment changes. In composite elements it results in generation of inelastic strains and redistribution of stress in cross-section.

The long term acting of timber-concrete composite elements can be analyzed in several ways. One of these is to use suitable commercial software product based on the Finite Element Method and the other possibility is applying differential equations to obtain real response of these structural elements, as it is presented by Schlänzlin [1] and by Fragiacomo [2]. The numerical methods which include different rheological models take into consideration the time dependent behaviour and therefore they are inappropriate in common design practice.

The carrying capacity of bending composite wood-concrete element can be determined for example by calculation of effective bending stiffness considering the flexure of connection according to Additions B of EN 1995-1-1, Design of Timber Structures. This calculation, however does not sufficiently consider the rheological properties of composite materials, shrinkage, bulking of materials, the influence of composite on the creep coefficient and at last the influence of environmental changes.

Due to the theoretical and experimental analyses the analytical calculation model of bended timber-concrete composite element was derived under long term loading with linear material behaviour. The derived model takes into consideration the creep of wood, concrete and fasteners, mechano-sorptive creep of wood, shrinkage of concrete and thermal and humidity environmental changes. Applying this theoretical model and experimental tests on timber-concrete composite beams with long term loading there will be described the influence of rheological behaviour on long term acting of these members..

2. The analytical calculation model

The developed analytical calculation model is based on the linear elastic solution applied in Eurocode 5, Annex B for the design of mechanically jointed beams. The visco-elastic creep of concrete according to the EN 1992-1-1 is inserted to the calculation of the effective bending stiffness. The visco-elastic and mechano-sorptive creep of wood is also involved in the form of the rheological model developed by Toratti [3].

For the shear connections with mechanical fasteners the following expression of creep coefficient is proposed:

$$\varphi_s = 2\sqrt{\varphi_c . \varphi_t}\,, \tag{1}$$

where φ_c is creep coefficient of concrete, φ_t is creep coefficient of wood.

Expression (1) considers creep of both connected materials and can be used for the calculation of creep coefficient in case of different shearing fasteners. The suitability of the proposed expression (1) was confirmed by comparison with experimental results received from works of Kenel and Meierfofer [4] and Michelfelder [5].

Connecting the concrete layer to timber element the shrinkage of concrete is prevented by the timber, which leads to increase of deflection of timber-concrete composite beam. In cross- section the concrete shrinkage causes the eccentric force. The influence of this force on the stress distribution in the cross- section depends on the stiffness of fastening which is characterized by γ coefficient of fastening stiffness.

The stress distribution in timber-concrete cross-section affected by concrete shrinkage can be calculated according to Fig. 1, using the following expressions:

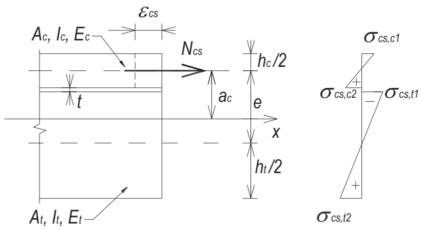

Fig. 1. Stress distribution in composite cross- section affected by concrete shrinkage

$$\sigma_{cs,c} = \gamma\,\varepsilon_{cs}\,E_c\left(1 + \frac{E_c A_c a_c}{(EI)_{eff}}\left(\pm 0{,}5h_c - \gamma\,a_c\right) - \frac{E_c A_c}{E_c A_c + E_t A_t}\right) \tag{2}$$

$$\sigma_{cs,t} = \gamma\,\varepsilon_{cs}\,E_c\left(+\frac{E_t A_c a_c}{(EI)_{eff}}\left(\pm 0{,}5h_t + a_t\right) - \frac{E_t A_c}{E_c A_c + E_t A_t}\right) \tag{3}$$

The deflection in the beam middle span affected by concrete shrinkage will increase by the following value:

$$\delta_{cs} = \frac{\gamma\,\varepsilon_{cs}\,E_c A_c a_c}{(EI)_{eff}} \cdot \frac{L^2}{8}\,. \tag{4}$$

where ε_{cs} is strain of concrete affected by shrinkage, γ is stiffness coefficient of fastening, E modulus of elasticity (index c) for concrete or (index t) for wood, A area of concrete or wood cross section, $(EI)_{eff}$ effective stiffness of the composite cross- section in accordance with EN 1995-1-1 Annex B, h depth of concrete or wood cross- section, L span of the composite beam, a_c, resp. a_t see Fig 1.

Analogically to formulae (2), (3) and (4) there were derived the expressions for stress distribution in timber-concrete cross- section and for the deflection in the middle span affected by the temperature and moisture content changes of environment.

The derived calculation model enables to predict the time dependent stress distribution in cross- section and time dependent deflection curve in the middle span of simply supported timber-concrete composite beam.

3. Experimental test

In the time period from 2005 to 2010 the long term experimental bending tests were carried out on two types of timber-concrete composite beams.

The first type of composite system is presented by 5,0 m long and 600 mm wide beam, created from three separated longitudinal vertically oriented timber planks (grade C22) with cross- section 45 x 220 mm. The planks were covered by 15 mm thick OSB sheet. The thickness of the concrete layer was 50 mm. The problem of this composite system, mainly from the point of view of long term action, is the shrinkage of the wood and concrete respectively.

To eliminate the influence of this phenomenon, steel fiber reinforced concrete was used for beam specimens. This type of reinforcement, in addition to eliminating the cracks due to shrinkage of concrete, also improves the strength parameters of the concrete layer, which leads to a high performance composite action of

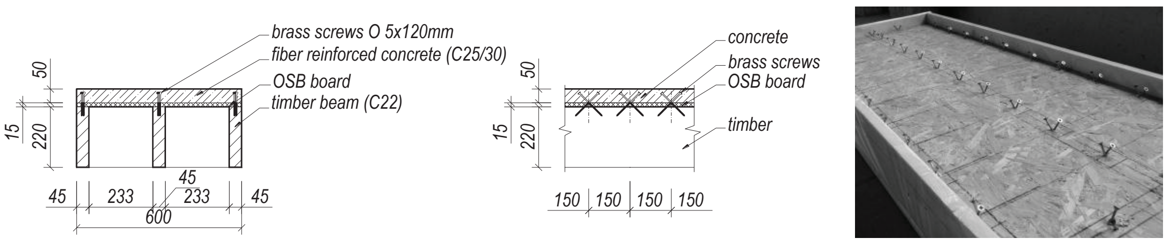

Fig. 2. a) Cross-section and shear connection of experimental beams Type 1; b) Preparing of specimens

the beam. The shear connection between the concrete and planks is performed by common wood screws with 5 mm diameter and 120 mm length. The distance between the screws along the planks is 150 mm. In each position a pair of screws was driven in with a slope of 45° to the planks top edge (Fig. 2).

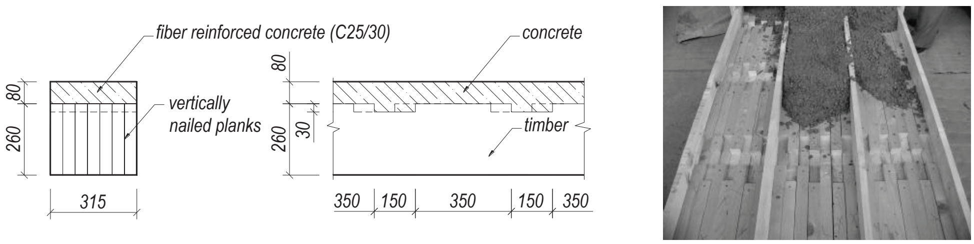

Fig. 3.Cross-section and groove connection of experimental beams Type 2; b) Preparation of specimens

The second type of investigated composite timber-concrete system is a beam with vertically nailed planks. The 5 m long beam with 340 mm depth and 315 mm width of cross- section was built from 7 vertically nailed timber planks 45 x 260 mm cross- section. The thickness of the fiber reinforced concrete layer is 80 mm and the grooves depth is 30 mm. The length and number of grooves were determined by preliminary calculation. Softwood – spruce with grade C22 and concrete with grade C25/30 were applied. To decrease the influence of wood shrinkage to the groove connection, in each second timber planks the grooves position was shifted by the half length of the groove (Fig. 3).

The required mechanical parameter of applied wood, concrete and shear connections was determined separately according to the relevant standards. Four point bending test with long term constant static loading was carried out on each beam specimen. Three beams of each composite beam type were tested. In the middle of beam span the vertical sag was gauged. The experiment takes place in interior, moreover humidity and temperature of the environment was denoted.

4. Analysis of theoretical and experimental results

The suggested calculation model was applied for the analysis of experimental test results. Theoretical deflections in the middle span for beams Type 1 and Type 2 in time period of tests were calculated. Fig. 4 shows, that the theoretical results are well fitted with experimental data. Fig. 4 also indicates that the timber-concrete composite beams are very sensitive to the moisture content of the environment. The beam Type 1 is reacting to the moisture change more promptly than the beam Type 2. It is caused by their different timber parts. The massive wood deck from vertically oriented plates in Type 2 is not so sensitive to the moisture changes than the separated timber beams.

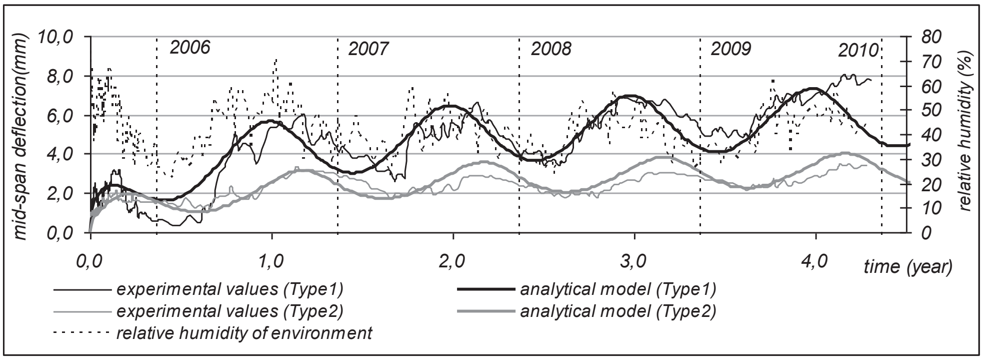

Fig. 4. Comparison of experimental and theoretical mid-span deflections of beams in time

The increase and decrease of the mid-span deflection of composite beam under long term load depends on the conditions of the environment. The beginning of the loading tests of composite beams was in summer with high level of environmental humidity and the mid-span deflection of beams increased. After some months, in winter time, the level of humidity decreased and also the mid-span deflection was decreased. These types of movements are regular periodic deviations of deflection but they are not the permanent part of deflection.

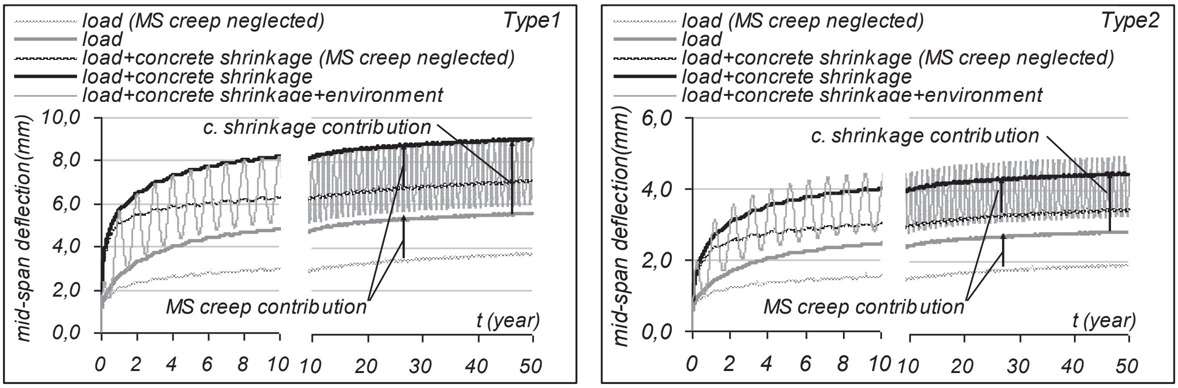

Fig. 5. Contribution of various rheological phenomena to final deflection of experimental beams a) Type1; b) Type2

Fig. 5 demonstrates the contribution of individual rheological affects to the final deflection of both types of beam specimens. At both types of beams the mechano-sorptive creep affects approximately the 30% increase of final deflection and shrinkage affects around 37% of increase related to the deflection caused by external load.

5. Conclusion

The theoretical and experimental investigations of timber-concrete composite bended beam under long term loading have been carried out. In theoretical part the analytical calculation model was developed concerning the affect of rheological behaviour of wood, concrete and fasteners. Applying the calculation model the theoretical deflections of bended specimens were calculated. The obtained theoretical results of deflections were compared with the experimentally measured data to confirm the validity of the calculation model.

As the results of theoretical analysis show, the effect of the rheological behaviour of timber-concrete beam components to the final deflection under long term loading is significant. Therefore they can´t be neglected in the reliable design process of timber-concrete composite beams.

Acknowledgements

The author would like to thank for the support provided by VEGA Project No. 1/0865/11.

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